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Guideline for Selection of Systems, Structures and Components to be considered in Ageing PSA

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APSA

Network on Use of PSA for Evaluation of Ageing Effects
APSA Network Task 3
POS Task 4

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Abstract

This guideline intends to provide a practical approach and to recommend the methods to be used in selection/ prioritization of components, systems and structures (SSC) sensitive to ageing and important from risk point of view in operating nuclear power plants.

The approach intends to ensure that the selection process will be carried out and documented in a uniform and consistent manner.

The methods suitable for selection are briefly presented, and their advantages and disadvantages are specified.

A list of generic ageing mechanisms, the factors favorable for their occurrence and some sensitive materials are provided in appendices.

In the appendices are presented also the specific approaches and criteria used for SSC prioritization and selection in case studies performed in the frame of EC JRC Ageing PSA task 3 activities.

The guideline was developed in the frame of EC JRC Ageing PSA (APSA) Network activities.

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Chapter 1 INTRODUCTION

The aged components, systems and structures (SSC) can experience deterioration of their performances and by that to prejudice the safely operation of the plant.
Because of the large number of NPP SSC, the variety of their applications, the complexity of ageing processes, limited knowledge and limited resources, there is a need to concentrate the effort on the understanding and managing the impact of ageing mainly for the key aged SSC.

To identify the key aged SSC, their risk significance and their sensitivity to ageing should be evaluated (taking into account the risk implications, the various stressors contributing to performances degradation, the different ageing mechanisms and the available measures for detection of ageing degradation and for mitigation).

The available methods and approaches focused on the component and systems level, and do not offer too much about the impact of ageing on the overall plant safety level. Using PSA as a tool could bring important insights in this evaluation.

The first step in applying the PSA for evaluation of ageing impact will be the selection of the components which are both sensitive to ageing and important for modelling of initiating events or mitigation of accidents consequences.
This guideline is aimed to provide an approach about how to perform this selection.

The results of the selection would be the starting point for evaluation of ageing effects using PSA model and further analysis of data described in Guidelines for Analysis of Data related to Ageing of Nuclear Power Plant Components and Systems.

It is supposed that PSA model, components reliability and maintenance data collection system and necessary resources (competences and man-power) are available.

1.1 Objectives

This document is intended to provide a useful tool for the selection of risk-important SSC susceptible to ageing in operating nuclear power plants. It is aimed at applied scientists and engineers involved in performing the SSC selection process, for reaching the objective proposed.
The approach could be very useful in the process of risk-informed decision and in ageing management.

Chapter 2 SSC SELECTION AND PRIORITIZATION

Due to the fact that the effective evaluation and quantification of ageing degradation for all SSC does not represent a practicable approach (because of the large effort involved), the SSC should be carefully selected and prioritized to maximize the effective use of limited resources.[6]

A simplified approach is needed, and this guideline proposes to use an integrated decision-making process, which incorporates both risk and traditional engineering insights in the frame of expert panel. The results obtained by performing the following:

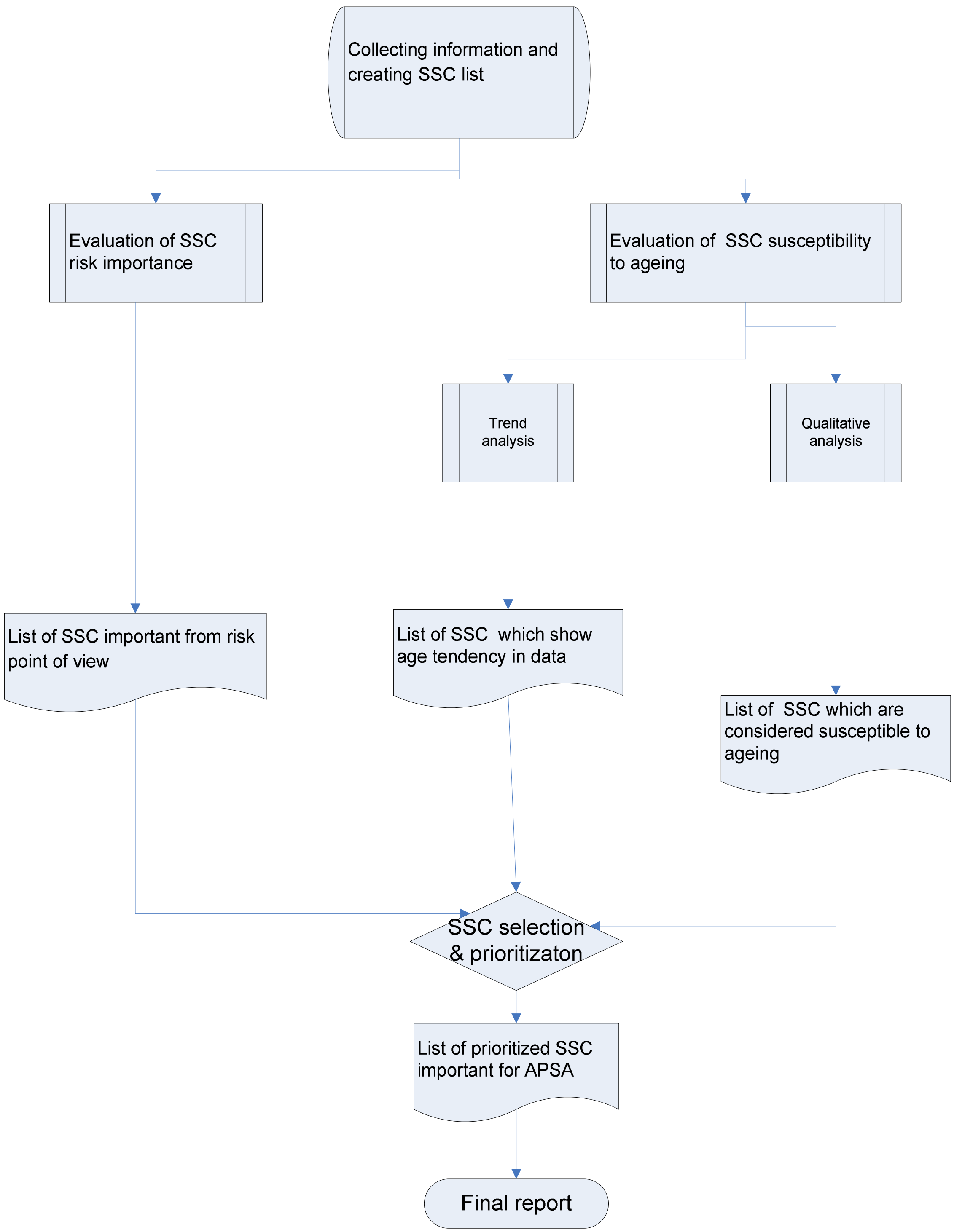
- Trend analysis,
- Qualitative analysis,
- Risk Importance Measures,

will be integrated in such manner that the final ranking (prioritization) of the SSC will incorporate both the risk significance, as the ageing susceptibility.

Such graded approach allows to avoid the unnecessary effort for quantification of ageing degradation when is not necessary (the time degradation effects are small).

Figure 1 shows the general work flow for the selection of SSC which are important for Ageing PSA (APSA) purposes, starting with establishment of initial list of components up to the final result, the prioritization of components regarding their risk-significance and sensitivity to ageing.

Figure 1 - Selection process for risk-significant NPP components which are susceptible to ageing


Collecting information and creating SSC list
Evaluation of SSC risk importance
Evaluation of SSC susceptibility to ageing
Trend analysis
Qualitative analysis
List of SSC important from risk point of view
List of SSC which show age tendency in data
List of SSC which are considered susceptible to ageing
SSC selection & prioritizaton
List of prioritized SSC important for APSA
Final report

The first step of the procedure is the systematic collection of necessary information and creation of initial list of components. This process is described in subchapter 2.1 of the guideline.

The second step of the procedure is represented by the evaluation of SSC from two points of view:

- susceptibility to ageing and
- importance from risk point of view.

The analysis of SSC susceptibility to ageing is necessary, considering that there is no reason to model the time-behaviour of SSC for Ageing PSA purposes if they do not have such vulnerability.
To identify the SSC potentially sensitive to ageing, the following techniques are proposed:

- trend analysis of available reliability data (described in subchapter 2.2 case 1) ,
- qualitative assessment or Ageing Failure Modes and Effect Analysis (AFMEA) (described in subchapter 2.2 case 2).

Qualitative assessment could cover SSC initially neglected in PSA models and SSC without enough failure statistics to perform trend analysis.

To identify the SSC which are modelled in PSA and are important from risk point of view, the Risk Importance Measures could be used. The process is described in subchapter 2.3.
All evaluation steps are consecutive and complementary. The steps need to be complementary due to the limitations and uncertainties associated with each of them.

After each of these steps, attributes concerning risk significance and ageing sensitivity will be allocated to each SSC.

The next step of the analysis is to prioritize the previously obtained results, using defined prioritization criteria. The final SSC list will contain the selected components which are sensitive to ageing (revealed by the presence of ageing trends or by the qualitative analysis) and important from risk point of view. This step is presented in subchapter 2.4 of the guideline.

The final step of the procedure is the documentation; a good documentation of the study results is mandatory, especially because of the benefits of the results for others activities. The format for presentation of results is described in subchapter 2.5 of the guideline.

2.1 Collecting information and creating initial list of SSC

Goal

This step provides the analyst with the necessary information to perform the analysis as the list of SSC which will be subjected to analysis.
The list should include the components already modelled in PSA, as others that were neglected or not directly modelled for different reasons, but are potentially important from ageing point of view.
This step is important since it determines the scope, defines the magnitude of analysis, and the level of effort, by determining what is included or not in the analysis.

Sources of information

- the available classification of SSC, considering the safety significance of the SSC, the safety-related and non-safety-related SSC. If the SSC cannot be related to any of the above classification, it should not be included on the list for further ageing evaluation.
- list of components modelled in PSA
- list of components considered for reliability data collection

The information from the above lists could be improved by additional sources, as the components included in ageing management program and risk-informed in-service inspection program (ISI).
All SSC needs to be grouped into groups, one group having similar design, similar operating conditions, similar degradation mechanisms, and similar surveillance and maintenance activities.
This is needed to assure the link with PSA model, for avoiding repeated evaluations for similar SSC, and also for accounting the common cause effect of the ageing on risk measures.

Results
Initial list of SSC to be evaluated

Format of presentation should include:
- components group, component type, component subtype, safety class
- list of components included in the group
- PSA attributes (modelled or not, level of modelling – basic event or initiating event, operating states and failure modes)
- operation and environmental conditions, stressors, maintenance or surveillance information

2.2 Evaluation of SSC susceptibility to age related failure

Goal
The identification of components which are sensitive to ageing
This step intends to evaluate the potential of ageing degradation to cause SSC failure.

If the operational data are enough, for identification of component susceptibility to ageing the ageing trend analysis should be performed. In case when no ageing trends were evidenced, or there are no sufficient statistically data, AFMEA could provide supplementary results for the decision-making.

Case 1 – using trend analysis

Objective

Trend analysis helps to identify which SSC have an increasing failure intensity (failure rate) in time, which could be an indication of ageing. Given a large population of SSC and a consolidated collection of operating experience data, statistical methods could be applied. The task of statistical analysis is to investigate whether the SSC failure rate is approximately constant.

Various statistical tests (graphs, nonparametric, parametric) could be used to check the assumption of constant failure rate (see subchapter 3.1).

Currently, most nuclear utilities have a good reliability data collection system and a large amount of data on safety-important components from probabilistic safety assessments (PSA). These data could be used for ageing analysis.

Sources of information
Operational data records (event reports, plant reliability databases, information from multipurpose data collection system)

Requirements

- ✓ large population of SSC
- ✓ long period of observation

Difficulties

Trend analysis could be performed only for the components with sufficient and good quality statistical data collected in a long period of observation. In practice, such data are available mostly for risk-important PSA components and some I&C components, and many others SSC have no sufficient data from statistical point of view.

In many cases, the failure data are limited in number, there is no discrimination between the failures due to different degradation mechanisms and impact of testing and maintenance, and the available failure records are not adequate to identify degradation trends.

Results

Attributes for SSC sensitivity to ageing (revealed by the presence or not of ageing trends in data)

Format of presentation should include:

- ❖ components group, component type, component subtype
- ❖ statistical data characteristics (sample size, observation period, no of failures)
- ❖ type of statistical test
- ❖ results of trend analysis (presence or not of a trend, not-performed, significance level)

Case 2 – using qualitative analysis

Objective

Qualitative assessment is aimed to identify and characterize the link between the potential ageing mechanism and failure modes, and to demonstrate both the effect of failure on system reliability and the effectiveness of the surveillance strategy.

Ageing Failure Mode and Effect Analysis (see subchapter 3.2) should be used for identification of SSC sensitive to ageing, in the following situations:

- o operational data are sparse, and ageing trend analysis cannot be performed
- o no ageing trends were revealed (due to very high efficiency of mitigation measures)
- o for SSC not modelled in PSA models.

AFMEA evaluates the potential to degradation, by taking into account:

- *significance of possible ageing mechanisms*
- *ageing mitigation activities*
- *operating experience*

Sources of information

For short and medium lived, active components (relays, controllers, valves, pumps,) ageing information can be obtained from operating experience, including both failure and maintenance information.

For long lived, structural parts and passive components (pipes, cables, structures), there is no planned preventive or corrective maintenance, and ageing information is typically in the form of degradation data from condition monitoring, surveillance and inspections programs.

The participation of plant personnel in qualitative analyses represents an important aspect of the analysis, because it can reveal many issues, as failures that are not caused by ageing.

Difficulties

- ♦ the completeness of stressors list and potential ageing mechanism,
- ♦ large amount of information that should be consulted

The major problem of qualitative assessment is that is very time-consuming and resource-intensive.

Results
Attributes for SSC sensitivity to ageing (revealed by the AFMEA analysis)

Format of presentation should include:
- components group, component type, component subtype, failure mode
- ageing mechanisms associated to each failure mode
- consequences for each ageing failure mode
- test and maintenance efficiency
- risk priority number obtained for each of failure modes
- analysis performed or not

2.3 Evaluation of Risk Importance of SSC

Goal
Evaluation of SSC risk-importance

This step should evaluate the significance of SSC failure caused by ageing degradation, using either the PSA results or in case when is not available, the expert judgments.

Ageing degradation could cause either initiation of an accident sequence, or failure to operate on demand during mitigation of event, and these types of events could be modelled in PSA as initiating event or unavailability of a safety function. A particular component may be modelled in a PSA explicitly as a set of basic events with different failure modes or implicitly as a contributor to initiating events.

The analyst is interested in those SSC whose failure has the most significant impact on the selected risk measures. The appropriate measure to determine whether the SSC degradation may be important to risk is the Risk Achievement Worth, because if the risk impact is negligible even if the component fails, then the ageing of this component is not so important.
SSC for which the most significant gain in safety may be obtained when their reliability is improved could be characterized by the Fussell-Vesely importance.

If the screening criteria are met for either importance measure, the SSC should be considered as candidate risk-significant (see subchapter 3.3).

Risk importance for SSC modelled in PSA as basic events
Two standard PSA importance measures, Risk Achievement Worth (RAW) and Fussell-Vesely (F-V), can be used as screening tools to identify candidate risk-significant SSC (see subchapter 3.3).
For passive components, when RI-ISI results are available, the failures of piping segments as passive failures can be included into the PSA model. The conditional core damage probability (CCDP) could be used to give a measure of risk due to segment failure if failure of a given piping segment causes an initiating event, and will replace RAW in such cases. [14]

Risk importance to SSC modelled as contributors to IE [18]
The SSC contributing to initiating events may not be incorporated as basic components, but rather as grouped IE, and the importance of contributing SSC (RAW measure) is equivalent to importance of the IE. Therefore, all SSC should be mapped against modelled IE and corresponding RAW should be used for the Ageing PSA ranking purpose.
This process shall clearly identify the failure mode contributing to the initiating event, because it has further impact on screening of the ageing mechanisms.

Risk importance to SSC not modelled in PSA [18]
If a SSC is not modelled in the PSA, the numerical importance values are not available.
Taking into account that most of the SSC will contribute either to initiating events or to unavailability of mitigating functions already modelled, the failure modes of the SSC should be mapped against IE and basic events or safety functions modelled in the PSA and the corresponding RAW values should be used for the Ageing PSA ranking.

Sources of information
All available PSA models should be used, as for example:
- Full Power Internal Events PSA,
- Fire PSA,
- Seismic PSA or Seismic Margin Assessment,
- External Hazards PSA or Screening Assessment of External Hazards, and
- Shutdown PSA

Requirements
The PSA must be of sufficient quality and level of detail to support the evaluation process, and must be reviewed and updated as much as possible, to reflect the actual situation of the plant (all the replacements and renewals should be taken into account).

Results
List with selected components from risk importance point of view

Format for presentation should include:
- component group, component subgroup, component subtype, failure mode
- RAW
- FV
- threshold value
- attributes of selection (selected or not)

Difficulties
The PSA model does not include necessary all the components needed to be assessed from degradation point of view. Components not included in the model would not be considered, despite the fact that they may be contributors to risk increasing as they ageing.
When possible, the PSA model should include the external events effects, in order to calculate the risk importance measures for passive components also.
The importance of particular SSC could change in time.

2.4 Prioritization

Goal
The prioritization of the results obtained in the previous steps.

Objective
This step performs the revision of the results obtained in previous steps and prioritization of SSC using specific criteria.
The SSC will be scored for specific criterion and be ranked relative to one another. The decision criteria should be defined very clearly, in order to minimize the subjectivity. The steps for performing the process are presented in subchapter 3.4.

The results of AFMEA or ageing trend analysis will be combined with the results of risk-significant measures in a decision table, using specified criteria in the process of SSC selection for Ageing PSA purposes.

Requirements

- ✓ trend analysis results,
- ✓ AFMEA results,
- ✓ risk importance analysis results

Sources of information

All necessary information for a clear judgment (list of SSC, prioritization criteria, prioritization methodologies, and technical support material) are needed.

Results

List of SSC important for APSA purposes

Format of presentation should include:

- ❖ prioritization criteria and categories
- ❖ component group, component subgroup, component subtype
- ❖ results from trend analysis
- ❖ results from AFMEA
- ❖ results from risk importance analysis
- ❖ SSC ranking

2.5 Documentation of results

Objective

The report should provide an overview of the work performed.

The report should contain specifically the description of the work performed in each of the guideline steps, the methods and prioritization criteria used, the assumptions, and final results obtained.
The events will be ranked against each other even for cases where one event has a high risk significance and a low sensitivity to ageing, or vice versa.

The report should include all information specified at the previous steps of the guideline (see format of presentation for each step), and conclusions drawn from the results.
The information should be structured in a shape easily to follow.

Chapter 3 SSC SELECTION METHODS

The methods which can be used in determining risk significant SSC which are susceptible to ageing degradation are the following:

- trend analysis,
- qualitative analysis,
- evaluation of risk significance.

The methods are complementary and for the best results they should be used in combination.

3.1 Trend analysis

The simplest task of statistical analysis is to investigate whether the SSC failure rate is approximately constant. In case when is not constant, this could be a direct indication of ageing.

Various statistical tests could be used to validate or to refute the assumption of constant failure rate. According to the statistical technique used they can be divided into three groups: [1]

- graphs (visual evaluation),
- nonparametric hypothesis tests,
- parametric hypothesis tests.

The type of graph depends on the type of data (either data for the individual failures or binned data), and the assumptions about the renewal process.
A trend analysis of the data will be done by calculating failure rates for the components at various ages, and plotting them as a function of time. Any increase in the failure rate will indicate that ageing degradation may not be properly controlled.
In case of binned data, with component counts and failure counts aggregated into bins, for each bin, an estimate of λ will be made, using the maximum likelihood estimate (MLE - the number of failures divided by total exposure time for the bin) and treating λ as being constant within the bin. For each bin will be constructed a confidence interval for λ. After plotting the estimates and confidence intervals side by side, the analyst can look for a trend.
By providing visual assessment of data, the graphs help to easily identify ageing trends (increasing slope), but they don't give any quantitative estimation about the size of the trends.
The details for using graphical method are specified in Data guideline, chapter 3.1.2 [12]

The non-parametrical tests don't apply any assumptions concerning the type of random value distribution, they only check the validity of hypothesis H_0: no ageing occurs. Their results have to be always interpreted taking into account engineering considerations and qualitative assessment of data.

Different statistical tests (when the data contain information on the individual failures and when the data are aggregated in bins) could be used to validate or to reject this hypothesis. [1]
The detailed description of the tests that can be used and how they can be performed can be found in Data guideline, chapter 3.1.3 [12]

3.2 Ageing Failure Mode and Effect Analysis (AFMEA)

AFMEA is used to identify potential ageing failure modes, determine their effect on the operation, and identify actions to mitigate the failures. While anticipating every failure mode caused by ageing is not possible, should be formulated a list of potential failure modes as possible.

In case when classic FMEA results are available, the analyst should use them, by performing a selection related to failure modes caused by ageing and keeping as results only those created by ageing failure modes.

The following discrete steps shall be used in performing an AFMEA:

1. *Collecting necessary information*

The necessary information includes drawings, charts, descriptions, diagrams, component lists, internal and interface functions, expected performance at all indenture levels, and failure definitions.
Functional narratives should include descriptions of each mission in terms of functions which identify tasks to be performed for each mission, expected mission times and equipment utilization, and operational mode.
Anticipated environmental conditions for each mission shall be defined.

2. *Grouping of SSC and selection of the most representative item for each group*

The group should contain similar SSC, taking into account design characteristics, operational stressors and environmental conditions, as well as maintenance activities. The most representative components from ageing point of view should be the one that experiences higher stressor, or have smaller qualification.

3*. The identification of stress factors for each component and associated ageing mechanism*

In the process of identification of stressors and corresponding ageing mechanisms, the analyst should consider all information related to operating conditions, component design and qualification, material and manufacturer.

4. *The identification of all failure modes caused by ageing and specification of their effect on the immediate function or item, on the system, and on the mission to be performed*

Potential failure modes shall be determined by examination of item outputs and functional outputs. Failure modes shall be postulated on the basis of the schematics and functions required, and their effects should be identified.

5. *The evaluation of each ageing failure mode in terms of the worst potential consequences which may result and assigning a severity classification category*

The consequences of each assumed failure mode on item operation, function, or status shall be identified, evaluated, and recorded. Failure effects shall also consider the mission objectives, maintenance requirements and personnel and system safety. This information is taken into account in evaluating of ageing failure severity.

Ageing management practices have the potential for adequate control of ageing-enhanced plant risk, so analysis of ageing management practice represents an important factor for selection of SSC for Ageing PSA modelling. There are some cases when inspection and maintenance practice may be so

good on some components that their failure rate may be considered constant in time and there is no reason to develop age-dependent models.
The current ageing mitigating practices (monitoring, inspection, tests, maintenance, ageing management activities) should be evaluated for their adequacy for maintaining the risk contribution of these aged components within the acceptable value.
The existing stressors and current ageing mitigation practices are important in evaluation of probability of occurrence of ageing failure.

The following factors should be taken into account:

- the availability and adequacy of condition indicators to detect and predict components ageing degradation
- the adequacy of existing techniques to monitor these condition indicators
- the adequacy of existing operating and maintenance practices to mitigate components ageing degradation

Existing methods for inspection, surveillance and monitoring should be evaluated to determine whether they are effective for timely detection of ageing degradation before loss of safety function. Methods to be reviewed include testing, periodic inspection (both visual and instrument aided), on-line monitoring and data evaluation methods. This information is very important for evaluation of detection probability for ageing failure.
A description of the methods by which occurrence of the failure mode is detected by the operator shall be recorded (visual or audible warning devices, automatic sensing devices, sensing instrumentation, other unique indications, or none shall be identified).

The consequences of failure caused by ageing are evaluated by three criteria and associated risk indices:

- severity of potential ageing failure (S)
- probability of occurrence of a potential ageing failure (O),
- probability of detection within the process (D)

Each index ranges from 1 (lowest risk) to 10 (highest risk). The index ranges could be defined different from those mentioned, if it is desired. An example of indices quantification is provided in Appendix 5 – INR case study.

The overall risk of each failure is called *Risk Priority Number (RPN)* and represents the product of Severity (S), Occurrence (O), and Detection (D) rankings:

$$\text{RPN} = S \times O \times D \qquad (1)$$

The RPN (ranging from 1 to 1000) is used to identify the risk associated to each ageing failure and to prioritize the failures.

6. *The prioritization of components and providing recommendations to reduce ageing failure risk*

A prioritization of components based on RPN value obtained can be performed.
This step should determine recommended actions to lower the risk for failures that have a high RPN, usually by reducing likelihood of occurrence and improving controls for detecting the failure. These actions could include improvement of specific inspection, testing, maintenance or quality procedures; recommendation of different components or materials; limiting environmental stresses or operating range; monitoring techniques; and inclusion of back-up systems or redundancy.

7. *The documentation of analysis*

The results of the AFMEA shall be documented in a report that identifies the level of analysis, summarizes the results, documents the data sources and techniques used in performing the analysis, and includes the SSC group description, stressors, ageing mechanisms and worksheets.

A list of items omitted from the AFMEA shall be specified, justifying each exclusion.

The results of the analysis can be presented in a table as follows:

Table 1 – AFMEA information

System	Component	Ageing Failure	Effect of Failure	Severity Rating	Cause of Failure/ Ageing mechanism	Occurrence Rating	Means of Detection	Detection Rating	RPN	Remarks

Information sources

- operating experience, including both failure and maintenance information,
- degradation data from condition monitoring,
- personnel interviews.

The necessary data for performing the ageing analysis are the following:

- component and system information (including design modification and commissioning data)
- initial material condition and functional capability
- design service conditions and operating limits
- environment information (temperature, humidity, radiation) and environmental qualification specifications (qualified life, normal and DBE service conditions)
- operation mode (continuous, standby, intermittent), dates and profiles of component loading, cycling
- maintenance information (type of maintenance actions, date and duration, modification of maintenance methods and intervals, work description)

It is desirable that the necessary information should be structured in a shape that is easily accessible and readable (as possible, the information should be stored or transferred in electronic format).

Requirements

An understanding of the effects of various factors on degradation is needed, and knowledge of actual environmental conditions is essential for performing a good assessment.

Performing AFMEA involves another screening process, related to ageing mechanism, and requires knowledge of material properties and operating stressors for a specific components group.

The panel membership should represent expertise in a full spectrum of relevant technical areas: PSA, structures, electrical and mechanical components, component reliability, materials behaviour and failure analyses, in-service inspection, operations and maintenance, as well as safety, regulatory, ageing and life extension issues.
Members may be experts in more than one field.

The integrated decision process should, where possible, apply objective decision criteria and minimize subjectivity. A consensus process should be used for decision-making, and excessive reliance on any one member judgment should be avoided. Different opinions should be documented, recorded and resolved, if possible.

Experts have to answer for each component, to the following questions:

- Which are the stress factors?
- Which are the corresponding ageing mechanisms?
- What failure modes are induced by these ageing mechanisms?
- Which are the failure effects?
- Have examples of the problem been observed?
- How can be detected this type of failures?

The analysis can be developed by grouping components into groups if they have similar design, the same environment/ operating conditions and similar maintenance program.
Expert panel can be used to define SSC groups (component boundaries), operating conditions, and possible ageing mechanisms for SSC group.
It will be useful if a generic list will be available, with information about generic applicable degradation mechanisms and their effect on SSC performance.

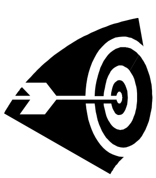
A list of ageing effects caused by service conditions, anticipated operational occurrences and environmental conditions is provided in Appendix 2.

A list of ageing mechanism, their influencing occurrence condition and susceptible material to specific ageing mechanism is provided in Appendix 3.

Since AFMEA includes (in indices quantification) considerations about maintenance efficiency to control the ageing process, as result it will be obtained the list of components which remained sensitive to ageing, despite the existing mitigation measures (maintenance, testing, surveillance).

Difficulties
There are question related to completeness of information. The limited information gives limits for the studies, because the analyst perform the analysis based on available documentation, and this is not always the same with the necessary one.
Many times, the maintenance history is not available. Since the degree of degradation is not recorded, maintenance records will need additive interviews with personnel and interpretation.

Advantages
The AFMEA will provide quick visibility of the more obvious failure modes caused by ageing/ degradation.
The method can be performed anytime in the system lifetime.



- permits identification of potential component/ process failure modes caused by ageing
- prioritizes system vulnerabilities to ageing
- provides guiding in improvement/ changing of operating condition
- permits identification of stress factors and provides recommendation for their decreasing
- emphasizes ageing prevention
- documents risk induced by ageing and actions necessary to reduce it
- provides justification for improving testing and maintenance activities
- complements Fault Tree Analysis and other techniques

All recommended actions which result from the AFMEA shall be evaluated for implementation or documented justification for no action.

AFMEA is useful mostly as a survey method to identify major failure modes in systems, but it is not able to discover complex failure modes involving multiple failures or subsystems, or to discover expected failure intervals of particular failure modes. For these, fault tree analysis is used.
The method doesn't take into considerations the human errors or the passive elements located in non-hostile environments, as well as static or non-loaded elements.

Performing the analysis will require lots of time, money, and effort, and the process can be extraordinarily tedious and time consuming in some situations.

3.3 Evaluation of SSC risk significance using PSA

Although ageing is not usually considered in the PSA calculations, the risk importance of assumed increases in the components failure probabilities can be evaluated. It is considered that if an increase in failure rate of certain components does not have any considerable effect, ageing analysis of such components are not necessary. [8], [10]
Risk importance measures are defined to evaluate a feature importance in further reducing the risk and its importance in maintaining the present risk level. Any type of feature can be evaluated for risk importance: safety functions, safety systems, components, mitigation functions. Evaluating the worth measures in a structured manner from general safety function worth measures to detailed component worth measures allows the focusing on the important items.
The SSC importance may be evaluated by applying risk-importance measures. [2], [3], [4], [7]
The most commonly used risk-importance measures are risk increase and decrease factors, and fractional contribution. [4]

Information sources
PSA model

Requirements

- ✓ PSA model,
- ✓ PSA software

Caution:
The limitation, assumptions and uncertainty of PSA should be considered when making risk-based decisions. Sensitivity analysis can be used to identify the importance of assumptions and areas where more in-depth analysis is needed.

Risk Achievement Worth

The risk achievement worth (RAW - the risk increase factor) represents the relative increase of the risk given the event (component, system train, system failure) occurs. [4]

$I_{RAW} = R_i^+ / R_o$ (2)

where

R_i - the increased risk level considering the event occurs

R_o - the present risk level

The features Risk Achievement Worth is useful for prioritizing features which are most important in reliability assurance and maintenance activities.

In calculating R^+_i , with event i occurred, it is important to consider other events which are also effectively occurred because of inter-relationships or dependencies with event i.

Fussell-Vesely Importance

The fractional contribution of a basic event to risk, Fussell-Vesely importance measure, expresses the relative improvement potential when it is assumed that the basic event never occurs, I_{FV}, and can be expressed as:

$I_{FV} = (R_0 – R_i^-)/ R_0$ (3)

where the numerator represents the risk due to contributor i. [4]

R_i^- - the decreased risk level considering that the event I will not occur

$I_{FV} = 1\text{-}1/D_i$ (4)

$D_i = R_0/ R_i^-$ (5)

The importance I_i is related to the risk reduction worth on a ratio scale, D_i. The risk reduction worth (the risk decrease factor) is formally defined to be the relative decrease of risk assuming that the basic event never occurs.

For a component, the risk achievement worth is calculated by substituting a value of unity for the component unavailability. The risk reduction worth is calculated by re-evaluation of Boolean equations substituting zero for the unavailability of that component. For subsystems, systems, or functions similar types of calculation and evaluations would be performed. The risk worth measures could be calculated according to a hierarchy where the risk worth measures for the system are calculated first, then the systems are successively broken down into subsystems, group of components and components.

Usually, the analyst uses dedicated software to perform these types of analyses.

For passive components, in case of RI-ISI results are available, the conditional core damage probability (CCDP) can be used to give a measure of risk due to segment failure if failure of a given piping segment causes an initiating event. The analyst can use CCDP instead of RAW in such cases, by establishing a correspondence between their values.

3.4 Ranking of SSC

The expert should, using the prioritization criteria, to rank the SSC relative to one another. Judgment is involved in many steps of the selection process, and mainly for synthesis/ integration of the results.

The prioritization will be performed in the following steps:

1) ranking of SSC according to results of risk importance measures

Using the results of risk importance measures, the analyst will include the SSC in one of the following categories:

- very important from risk point of view,
- important,
- not important or
- not evaluated/ modelled.

The allocation for one SSC into a category depends on the value of the importance measures, and on the prioritization criteria used.
SSC should be considered as being risk important if their calculated risk importance measure are above some specified values (for example, RAW >2, FV>0.005).

2) ranking of SSC according to results of trend analysis
Using the results of trend analysis, the analyst will allocate the SSC in one of the following categories:

- those that present ageing tendency (high trends),
- those that not shown any ageing signs (no trend), or
- not evaluated.

The allocation in one category or other depends on the results obtained after trend analysis was performed.

3) ranking of SSC according to results of qualitative analysis
Using the results of qualitative analysis, the analyst will categorize the SSC as follows:

- very sensitive to ageing (high impact of ageing on performances),
- sensitive to ageing (ageing has a moderate impact on SSC performances),
- not sensitive (ageing has a minimum impact on SSC performances) or
- not subjected to analysis.

The allocation in any categories depends on the results obtained after qualitative evaluation and on the criteria defined for prioritization.

4) final prioritization
The analyst will need to combine the results of these previous categorization, by determining which are the characteristics for the component that will be considered important for further analysis (for example, a component very important from risk point of view and very sensitive to ageing will be selected for sure).

In the appendices are presented different approaches of this prioritization.
The number of categories established for the first three steps to scale the SSC risk-importance or the sensitivity to ageing could vary (3, 4), taking into account the level of details, the scope of analysis, and available information.

Examples of the decision tables are provided in Appendix 5 and Appendix 4 of the guideline.

REFERENCES

[1] NUREG/CR-6823 - Handbook of Parameter Estimation for Probabilistic Risk Assessment, US NRC, Washington DC, USA, September 2003

[2] NUREG/CR-5248 – Prioritization of TIRGALEX- Recommended Components for Further Aging Research, US NRC, Washington DC, October 1988

[3] NUREG/CR-4144 – Importance Ranking Based on Aging Considerations of Components Included in Probabilistic Risk Assessments, US NRC, Washington DC, April 1985

[4] Nureg/ CR-3385 – Measures of Risk Importance and Their Applications, Washington DC, USA, July 1983

[5] IAEA-TECDOC-1147 - Management of ageing of I&C equipment in nuclear power plants, Vienna, June 2000

[6] IAEA, TRS no.338 – Methodology for the Management of Ageing of NPP Components Important to safety, Vienna, 1992

[7] Hiromitsu Kumamoto, Ernest J. Henley- Probabilistic Risk Assessment and Management for Engineers and Scientists, second edition, IEEE Press, Institute of Electrical and Electronics Engineers, New York, 1996

[8] IAEA-TECDOC-540 – Safety Aspects of Nuclear Power Plant Ageing, Vienna, January 1990

[9] EUR19843En - Safe Management of NPP Ageing in the European Union, May 2001

[10] K. Simola - Reliability methods in nuclear power plant ageing management, VTT 379, 1999

[11] IAEA, TECDOC-792 - Management of research reactor ageing, Vienna, March 1995

[12] Andrei Rodionov, Dana Kelly, Jens Uwe-Klügel - Guidelines for Analysis of Data Related to Aging of Nuclear Power Plant Components and Systems, September 2008

[13] NRC REGULATORY GUIDE 1.201 - Guidelines for categorizing structures, systems, and components in nuclear power plants according to their safety significance, rev.1, Washington DC, USA, May 2006,

[14] Nuclear Energy Institute - 10 CFR 50.69 - SSC Categorization Guideline, rev.0, Washington DC , USA, July 2005

[15] IAEA-TECDOC-670 - Pilot studies on management of ageing of nuclear power plant components Results of Phase I, Vienna, October 1992

[16] IAEA-TECDOC-1188 - Assessment and management of ageing of major nuclear power plant components important to safety: In-containment instrumentation and control cable, Volume I, Vienna, December 2000

[17] IAEA-TECDOC-1197 - Assessment and management of ageing of major nuclear power plant components important to safety: CANDU reactor assemblies, Vienna, February 2001

[18] A. Trifanov – Methodology for selecting SSC for time-dependent reliability modeling in PSA, ANS PSA2008 Topical Meeting “Challenges to PSA during the nuclear renaissance”, Knoxville, Tennessee, September 7-11, 2008

APPENDIX 1 – DEFINITIONS

Ageing – the general process in which characteristics of a structure, system or component (SSC) gradually change with time or use (definition according to EPRI Common Ageing Terminology). It is most commonly used with a connotation of changes that are (or could be) detrimental to protection or safety, i.e. as a synonym of ageing degradation.

- the continuous time dependent degradation of materials due to normal service conditions, which include normal operation and transient conditions; postulated accident and post-accident conditions are excluded (IAEA definition)

Fault - incapacity to function in a desired manner, or operation in an undesired manner, regardless of cause

Failure - incapacity or interruption of ability of an SSC to function within acceptance criteria

Ageing failure - failure whose root cause is ageing

Dormant State - the failure appears when the component is not working (no matter if the system that includes it is functioning or not).
A component is considered in dormant state if its failure can be detected (observed) only by testing or by means of an indication for its state/position.

Run State - the failure appears when the component is in function.
A component in run state means that its failure can be detected (observed) as a result of its effects on a system, no matter whether or not it belongs to.

Failure on Demand - failure of a component to respond as needed

Standby Failure - the failure occur during the non-operational period, preventing operation when required.

Operational failure - the system or component is normal operating or start successfully but fail to continue to operate for the required period of time

Failure cause - the physical or chemical processes, design defects, quality defects, part misapplication, or other processes which are the basic reason for failure or which initiate the physical process by which deterioration proceeds to failure

Failure mode - the manner in which a fault occurs, i.e. the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent

Failure effect - the consequence of a failure mode on an operation, function, status of a system/ process/ activity/ environment
The effect may range from relatively harmless impairment of performance to multiple fatalities, major equipment loss, and environmental damage, for example. Failure effects are classified as local effect, next higher level, and end effect

Ageing effects - net changes in characteristics of an SSC that occur with time or use due to ageing mechanisms

Ageing degradation - the ageing effects that could impair the ability of a SSC to function within the acceptance criteria

Stressor - agent or stimulus that stems from pre-service and service conditions and can produce immediate or ageing degradation of an SSC

Ageing mechanism (synonym to **degradation mechanism**) - specific process that gradually changes characteristics of an SSC with time

Criticality - relative measure of the consequences of a failure mode and its frequency of occurrences

Criticality analysis (CA) - procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence

Severity - the consequences of a failure mode
Severity considers the worst potential consequence of a failure, determined by the degree of injury, property damage, or system damage that could ultimately occur.

Detection mechanism - the means or methods by which a failure can be discovered by an operator under normal system operation or can be discovered by the maintenance crew by some diagnostic action

Failure mode and effects analysis (FMEA) - procedure by which each potential failure mode in a system is analyzed to determine the effects on the system and to classify each potential failure mode according to its severity

Ageing Failure Mode and Effect Analysis (AFMEA) - an inductive analysis that systematically details, on a component-by-component basis, all possible failure modes caused by ageing and identifies their resulting effects on the plant

Parametric - in parametric inference, the data are assumed to come from a known distributional form, with only the parameters unknown. Parametric statistical inference is concerned with learning the values of unknown parameters (and their associated properties) from sample data for a given or assumed family of distributions.

Nonparametric - in nonparametric inference, no distributional form is assumed. The values of the parameters are unknown, as well as the form of the distribution.

Hypothesis - statement about the model that generated the data.
If the evidence against the null hypothesis, H_0, is strong, H_0 is rejected in favour of the alternative hypothesis, H_1.
If the evidence against H_0 is not strong, H_0 is "accepted"; that means it is not necessarily believed, but it is given the benefit of the doubt and is not rejected.

APPENDIX 2 – AGEING EFFECTS

Table A2.1 - Effect of ageing for several service conditions [11]

Condition	Ageing mechanism	Consequence
Radiation	Properties modification	- chemical decomposition - strength changing - ductility changing - color changing - swelling - resistivity changing - burnup
Temperature	Properties modification	- strength changing - resistivity changing - ductility changing - color changing
Stress (pressure)	Creep	- changes of geometry (e.g. break, collapse)
Cycling of temperature, flow and/or load Flow induced vibrations	Motion Fatigue Wear	- displacement - change of position or set point - loose connections - break, collapse - deformation - deterioration of surface - modification of dimensions
Flow	Erosion	- strength changing
Fluids chemistry	Corrosion/galvanic cells	- release of radioactive material - strength changing - deposition of particles - short circuits - leakage conditions

Table A2.2 - Effect of ageing for anticipated operational occurrences [11]

Condition	Ageing mechanism	Consequence
Power excursion	Thermal and mechanical damage	-deterioration of systems -accelerated ageing
Flooding	Deposition and chemical contamination	-corrosion
Fire	Heat, smoke, reactive gases	-reduction of strength -corrosion

Table A2.3 - Effect of ageing for several environmental service conditions [11]

Condition	Ageing mechanism	Consequence
Humidity, salinity	Corrosion/galvanic cells - leakage	- release of radioactive material - strength reduction - deposition of particles - short circuits
Chemical agents	Chemical reactions	- undesirable chemical products - deterioration of structures
Wind, dust, sand	Erosion and deposition	- strength changing - deterioration of surface - malfunction of components

APPENDIX 3 – AGEING MECHANISMS, FACTORS FAVORABLE TO THEIR OCCURRENCE AND SUSCEPTIBLE MATERIALS

[5], [8], [11], [15], [16], [17]

EMBRITTLEMENT

Ageing mechanism subtype: Thermal embrittlement

Factors of influence: High temperature

Susceptible materials:

- Ferritic stainless steels
- Cast stainless steels

Ageing mechanism subtype: Hydrogen embrittlement

Factors of influence: Low temperature

Susceptible materials:

High strength, low alloy components, vessel cladding (ferrite phase) interface between vessel cladding and vessel, anchor bolts, vessel and pressurizer supports

EMBRITTLEMENT

Ageing mechanism subtype: Irradiation embrittlement

Factors of influence:

- type of material, material chemical composition
- heat treatment
- initial mechanical properties
- irradiation energy and time of exposure of material

Strong irradiation and long exposure are favorable for occurrence of embrittlement.

- the neutron flux, the flux spectrum, the fluence, and the irradiation temperature

Susceptible materials:

- ♦ Metals, only in case of fluence exceeding 10^{17} cm^{-2}, and high temperatures usually above 400°C.
- ♦ Zirconium alloys for fuel cladding and CANDU pressure tubes
- ♦ Austenitic stainless steel for reactor pressure vessel internals and reactor pressure vessel cladding
- ♦ Fine grained high strength carbon steel for the reactor pressure vessel shell and CANDU feeder pipes
- ♦ Reactor pressure vessel, made in Low Alloy Steel, in the core region

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Ageing mechanism subtype: Insulation embrittlement

Factors of influence: Temperature

Susceptible materials:

Cables
Motor windings
Transformers

THERMAL AGEING

Ageing mechanism: Thermal ageing

Description: gradual and progressive changes in the microstructure and properties of a material exposed at an elevated temperature for an extended period of time

Factors of influence:

- level of temperature (temperature between 400 and 600^{0}C)
- material state (micro-structure)
- time

Susceptible materials:

For Ferritic Steels, the effect of thermal ageing results mainly from intergranular segregation of residual impurity elements (e.g. Phosphorous). This leads to a hardening of the material and a reduction of the fracture toughness.

Cast Austenitic-Ferritic Stainless Steels (duplex structures) and Martensitic Stainless Steels are susceptible to thermal ageing in the normal operating temperature range of PWRs, by "unmixing" of chromium from its solid solution in the ferrite of the duplex structure and in martensite.

Organic materials (e.g. electrical cables) degrade due thermal ageing leading to changes in mechanical properties (e.g. hardening) and cracks initiation.

In case of excessive temperature, metal can be overwarmed and perturbation or even cracks could appear in microstructure.

CREEP

Ageing mechanism: Creep

Description: time and load dependent plastic deformation of the material

Factors of influence:

- stress
- time
- material (grain size, impurities, precipitations, secondary phases)
- temperature

High temperature favorizes the process.

Susceptible materials:

Pre-stressed or post-tensioned structures

For metallic materials creep becomes a matter of technical concern when the operating temperature exceeds about 40% of the absolute melting temperature of the material.

Vessel internals (radiation assisted)

FATIGUE

Description: progressive localized permanent structural change that occurs in a material subjected to repeat or fluctuating strains at stresses having a maximum value less than the tensile strength of the material

Ageing mechanisms subtypes:

- Low cycle fatigue (number of cycles before rupture N < 10^4 cycles, plastic macroscopic deformation following each cycle)
- High cycle fatigue (N > 10^4 cycles, elastic macroscopic deformation)
- Corrosion fatigue (different from corrosion because the stressors are cyclic type, not static)

Factors of influence:

- Loading situation
  - mode of loading - tension, compression, torsion
  - level of loading - mean stress, stress amplitude

There is a correlation between applied stress amplitude and the number of load cycles to failure. The lower the macroscopic stress peaks, the higher is the number of cycles to failure.

- Material

The fatigue strength increases welds and other material inhomogenities, internal imperfections surface flaws cause a decrease in fatigue strength.

- Design and surface quality

Local structural discontinuities, cracks and notches act as stress concentrators and reduce the fatigue strength.
Surface roughness reduces the fatigue strength.

- Residual stresses

Compression stresses have a positive effect on the fatigue strength, tension stresses have a negative effect.

- Environment

Temperature affects the fatigue strength as the tensile properties (yield and ultimate strength) decrease; corrosion gases or liquids can drastically reduce the fatigue strength.

Susceptible materials:

- Rotating equipment supports
- Piping attached to large components

Piping are sensitive especially to low cycle fatigue.
Piping nozzles, mixing tees and elbows are sensitive especially to high cycle fatigue.
Thermal mixing regions, especially carbon and alloy steels are sensitive especially to corrosion fatigue.

CORROSION

Description: the reaction of a metal with its environment that causes a detectable change in the material and can lead to deterioration

Corrosion without mechanical loading

Ageing mechanism subtype: Uniform corrosion

Factors of influence:

- Fluid oxygen content
- Temperature
- Flow rate

Susceptible materials:

- Carbon or Low Alloy Steels exposed to boric acid leakage
- Crevices and hideout regions
- Low and no flow components
- Safety injection systems
- Service water systems

Ageing mechanism subtype: Selective corrosion

Factors of influence:

Existence of distinct material phases/ regions adjacent to the grain boundaries or specific alloying elements

Susceptible materials:

Multi-phases structure, e.g. Cu-Al alloys in contact to polluted or see water

CORROSION

Corrosion without mechanical loading

Ageing mechanism subtype: Local corrosion (include pitting, crevice corrosion)

Factors of influence:

- inhomogenities at the metal surface
- local differences in the electrochemical reactivity of the environment

Pitting is commonly caused by the breakdown of the passive film on a metal, in local areas, by species such as chlorides.

Crevice corrosion results from local environment conditions in the restricted region of a crevice being different and more aggressive than the bulk environment.

Galvanic corrosion occurs when two metal with different electric potential are in contact. The highest the electrochemical potential, the stable related to corrosion galvanic is the material. Galvanic corrosion is influenced by:

  - Type, surface state and material composition
  - Solution pH
  - Electric potential at metal - electrolyte boundary
  - Aggressive chimique species (Cl^- - see water)

Susceptible materials:

Pitting may occur at critical location such as tube-to-tube sheet joints of the Steam Generators, where fluid velocities are stagnant or low (i.e. impurity concentration can occur).

Gold is a noble metal, is not sensitive to galvanic corrosion.

CORROSION

Corrosion with additional mechanical loading

Following conditions should be present in the same time:

- stressors (aggressive environment from chimique point of view -water pH, intense mechanical stressors, intense neutronic irradiation)
- material microstructure sensible (Ni composition in alloy)
- high temperature for increase the reaction kinetic

The temperature should be higher then 80/100°C for occurrence of the mechanism.

The following material are sensitive to this type of corrosion:

- Ni alloys (inconel 600)
- inoxidable alloy in contact with primary environment

Ageing mechanism subtype 1: Stress Corrosion Cracking (SSC)

Factors of influence:

Combination of:

- tensile stress
- aggressive environment
- susceptible material.

Susceptible materials:

Weld or flaw vicinity in components (tensile stress and off-normal chemistry conditions)

Components near leaking valves (insulation)

Ageing mechanism subtype 2	**Occurrence factors**	**Sensible materials**
Intergranular Stress Corrosion Cracking (IGSCC)	• Sensitivity of material function of his composition and structure • Environment pH and composition (oxygen, clorure content can be in favor of the phenomenon) • Temperature and exposure time Anodic stress corrosion cracking occurs as a combination of the material, the environment and mechanical loading, in critical boundary conditions: ▪ the material must be sensitive to SCC; ▪ tension stresses must be sufficiently high; ▪ the environment must lead to a specific material reaction (carbon steel with nitrides or sulphide stringers austenitic steel with chlorides brass with ammonia)	Sensitized Austenitic Stainless Steels are susceptible to IGSCC in an oxidizing environment. Sensitization of unstabilised austenitic Stainless Steels is characterized by a precipitation of a network of chromium carbides with depletion of chromium at the grain boundaries, making these boundaries vulnerable to corrosive attack.
Transgranular Stress Corrosion Cracking (TGSCC)	Aggressive chemical species especially if coupled with oxygen and combined with high stresses.	
Primary Water Stress Corrosion Cracking – form of IGSCC (PWSCC)	Condition of intergranular cracking in primary water within specification limits (i.e. no need for additional aggressive species).	Systems that usually have good resistance to uniform corrosion, such as austenitic stainless steel with passive layers. SCC can be observed in such steels in combination with pitting.
Irradiation Assisted Stress Corrosion (IASCC)	IASCC requires stress, aggressive environment and a susceptible material. In case of IASCC, a normally non-susceptible material is rendered susceptible by exposure to neutron irradiation.	PWR internal components (e.g. baffle bolts) Reactor pressure vessels and internals

CORROSION

Corrosion with additional mechanical loading

Ageing mechanism subtype 1: Strain induced corrosion cracking (SICC)

Factors of influence:

Simultaneous action of:
- temperatures above 150°C
- oxygen content in the water greater than 50 ppb
- strain rate of the order of 10^{-4} s^{-1}

Susceptible materials:

Piping and vessels of unalloyed or low alloyed ferritic steels in high purity water and water in boiling water reactors

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Ageing mechanism subtype 1: Corrosion fatigue

Factors of influence:

- characteristics of the corrosive environment, such as the pH value, the temperature, the electrochemical potential or the oxygen content in water
- the loading frequency and wave form
- the mean load and the load amplitude as expressed by the R ratio (R = Kmin/Kmax)
- sulphur content of steel
- time

Susceptible materials:

Parts in motion, such as the shaft of the main coolant pump
Piping affected by motional parts or flow vibration
Structures subjected to thermal transients caused by start-up and shut-down, cold water

CORROSION EROSION
FLOW ACCELERATED CORROSION (FAC)

Ageing mechanism type: Flow Accelerated Corrosion (FAC)

Description: material removal process resulting from a corrosive process supported by a mechanical component (flowing liquid or gas) whereby the flow removes the passivity layer or prevents the buildup of such layers

Factors of influence:

- Material
- Water chemistry

In alkaline water the corrosion erosion process is less severe than in acidic water. At pH values greater than 9.5 practically no corrosion erosion occurs. If this pH value is reached by means of ammonia dosage, secondary effects have to be considered, such as stress corrosion cracking in condensate tubes made of copper alloys.

- Temperature

A maximum susceptibility has been observed at a temperature of about 150°C. Under 300^{0}C, the phenomenon can be considered null.

- Flow velocity

The material removal process increases exponentially with increasing flow velocity. The design and fabrication have great influence on the micropattern of flow and thus on the local increase on the critical threshold velocity.

The corrosion process would not occur or would take place at a significantly lower rate if the mechanical component (erosion) was not acting.

Susceptible materials:

- Steam piping and steam separation
- Heat exchangers
- Turbine blades
- Carbon and Low-Alloy Steels

Unalloyed carbon steels are sensitive; steels with chromium content greater than 2% are most resistant.

MICROBIOLOGICALLY INFLUENCED CORROSION (MIC)

Ageing mechanism type: Microbiologically Influenced Corrosion (MIC)

Description: accelerated corrosion of materials resulting from surface microbiological activity

Factors of influence:

- high temperature of the environment
- long exposure time of material in corrosive environment
- pressure, environment chemistry, pH and oxygen presence
- sediments presence

Susceptible materials:

Any buried system or system using untreated water is susceptible to MIC.

Carbon Steels and, to a lesser extent, Stainless Steels and Nickel alloys

Many metals are sensitive to this type of corrosion (Fe, steels, inoxidable steels, Al alloy). Ti, Zr, Tn are resistant to this type of degradation. Presence of Mb or Cr into steel composition decrease considerable the corrosion kinetic.

Service water, heat exchangers, equipment where pressure tests are performed, equipment laid up, anchor bolts, diesel generators

WEAR

Definition: loss of material as a result of mechanical contact between two solid surfaces under relative motion

Factors of influence:

- mechanical contact between two solid surfaces under relative motion –due to vibration, sliding or due to presence of foreign objects
- time

Susceptible materials:

Plastics, steels, non-ferrous metals, hard metals, ceramics and various coatings. Areas of concern are those with the following conditions:
- Designed relative motion (sliding, rolling), e.g.:
    - guiding tubes
    - valves
    - engine parts of different types
    - electrical relays and contacts
- Flowing liquids, gases or two phase flows with or without abrasive contaminants, e.g.:
    - pipes, tubes
    - valves
    - steam turbine blades and casings
- Vibration of fitted parts:
    - sleeves
    - steam generator tubes
    - turbine blades

Adhesive wear - two surfaces which slide against each other under pressure
The wear rate of adhesive wear can be increased with increasing pressure of one surface against the other.

Abrasive wear - presence of hard particles which slide or roll under pressure across a surface
The wear rate of abrasive wear can be increased with the number, size, and hardness of the particles, and with the pressure and speed of movement between the two surfaces.

Erosive wear - a surface which is in contact with a fluid in relative motion to the surface that may contain particles. This type of wear most often involves solid particles, though one variation of this type, liquid-impingement erosion, is caused by liquid droplets that are carried in a rapidly moving stream of gas.
The wear rate of erosive wear can be increased with the force of the particles on the surface and with the speed of movement of the fluid

Surface fatigue wear - a surface that is experiencing high cyclic contact stresses and from whom particles of metal are detached.

The wear rate of surface fatigue wear can be increased with the force, frequency, and duration of the contact forces

Fretting - two surfaces in contact, subjected to repeated, extremely small amplitude sliding, especially in the presence of oxygen. The phenomenon is characteristic to rotating equipment.
The wear rate of fretting can be increased with the force, frequency, and duration of vibration.

Corrosive wear
The wear rate of corrosive wear can be increased with the severity of the chemical or electrochemical reaction, and with the synergistic effect of that reaction with the mechanical action.

APPENDIX 4 – JRC APPROACH

To identify and prioritize SSC potentially sensitive to ageing, the following technique was proposed:

- prioritize the SSC which are modeled in PSA using Risk Importance Factors,
- perform trend analysis of available reliability data,
- use qualitative assessment or Ageing Failure Modes and Effect Analysis (AFMEA) for a limited number of components.

All three steps are consecutive and complementary.
Table A4.1 provides an example of selection matrix, which applies the results from risk importance examination, trend assessment and qualitative analysis. A dash symbol in the table signifies that analysis couldn't be performed, as for example, for the components not modeled in PSA there is no Risk Importance evaluation, or the analysis is not needed, as in case of AFMEA when trend assessment give a positive result. The rank allocation for the SSC is presented at the end of the approach.

Table A4.1. Decision matrix for selection of SSC susceptible for ageing

Rank	Risk Importance	Trend in failure rate	AFMEA conclusion
1	High	Identified	-
2	High	-	Sensitive
3	High	Absent	Sensitive
4	Low	Identified	-
5	Low	-	Sensitive
6	-	Identified	-
7	-	-	Sensitive

The steps all need to be complementary due to the limitations and uncertainties associated with each of them.

Qualitative Assessment of Ageing Effects

The goal of AFMEA is to identify and characterize the link between potential ageing mechanism and failure modes. In addition, the results of the analysis help to postulate the assumptions concerning periodicity and degree of component renewal after the maintenance, as well, as related to the periodicity and effectiveness of failure mode control.
Procedure for Ageing Failure Modes and Effect Analysis consists of 8 major steps:

1) grouping safety and safety related components taking into account design characteristics, operational stressors and environmental conditions, as well as test and maintenance strategy,
2) in each group of similar components selection of most representative sample from ageing impact point of view (smaller design margins, higher operational loads, etc.),
3) for each representative sample identification and justification of all possible ageing mechanisms susceptible to appear in specific areas and zones of the component,
4) identification of failure modes (and it's effect to the system performance) which could occur due to the development of particular ageing mechanism,

5) ranking the ageing mechanisms against their possibility of occurrence and development up to the failure,
6) characterization of effectiveness of surveillance program (operational tests, inspections and maintenance actions) to control the ageing mechanisms and failure modes,
7) for each failure mode conclusions on

   - rank of effect of the failure mode and associated ageing mechanisms to the system and component performance (critical, non critical, etc.),

   - effectiveness of failure mode detection by operational tests and inspections,

   - degree of component renewal (elimination of ageing mechanisms effects) during preventive maintenance,

8) Documentation of results.

Figures 4.1 and 4.2 illustrate the results of steps 3, 4 and 5 of the procedure using as an example a stem gate valve of HPSI system. Figure 4.1 shows considered ageing mechanisms related to the different types of corrosion assigned for different areas and zones of the valve.

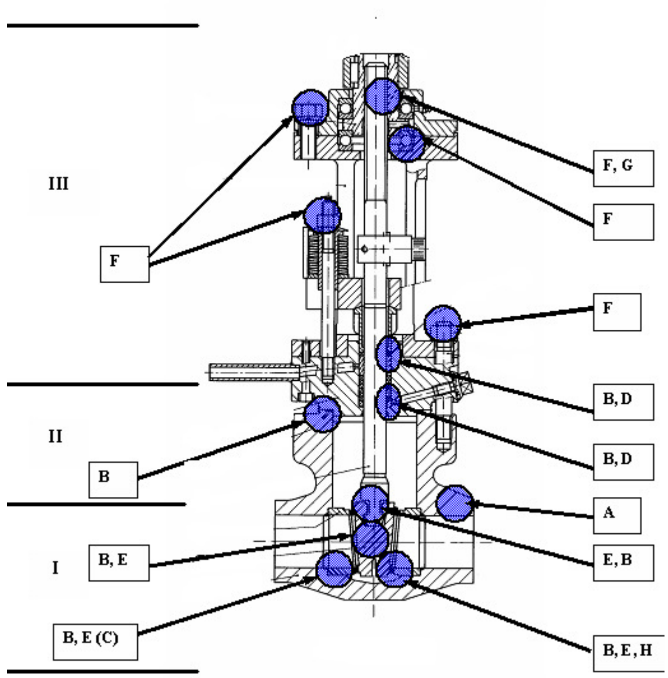


Figure 4.1 Example of stem gate valve initial identification of all possible ageing mechanisms (corrosions)

I – Area under pressure, full flow for a short time, fluid stagnant most of the time

II - Area under pressure, only occasionally flushed, fluid stagnant,

III – Area not in contact with working fluid.

A - general corrosion; B – Pitting and crevice corrosion ; C – Intergranular attack; D – Contact corrosion; E – Stress corrosion cracking ; F – Atmospheric corrosion ; G – Galvanic corrosion ; H – Fretting corrosion.

Last three columns in the table presented on Figure 4.2 indicate the ranking the ageing mechanisms ("criticality") against their possibility of occurrence ("probability") and development up to the failure ("importance").

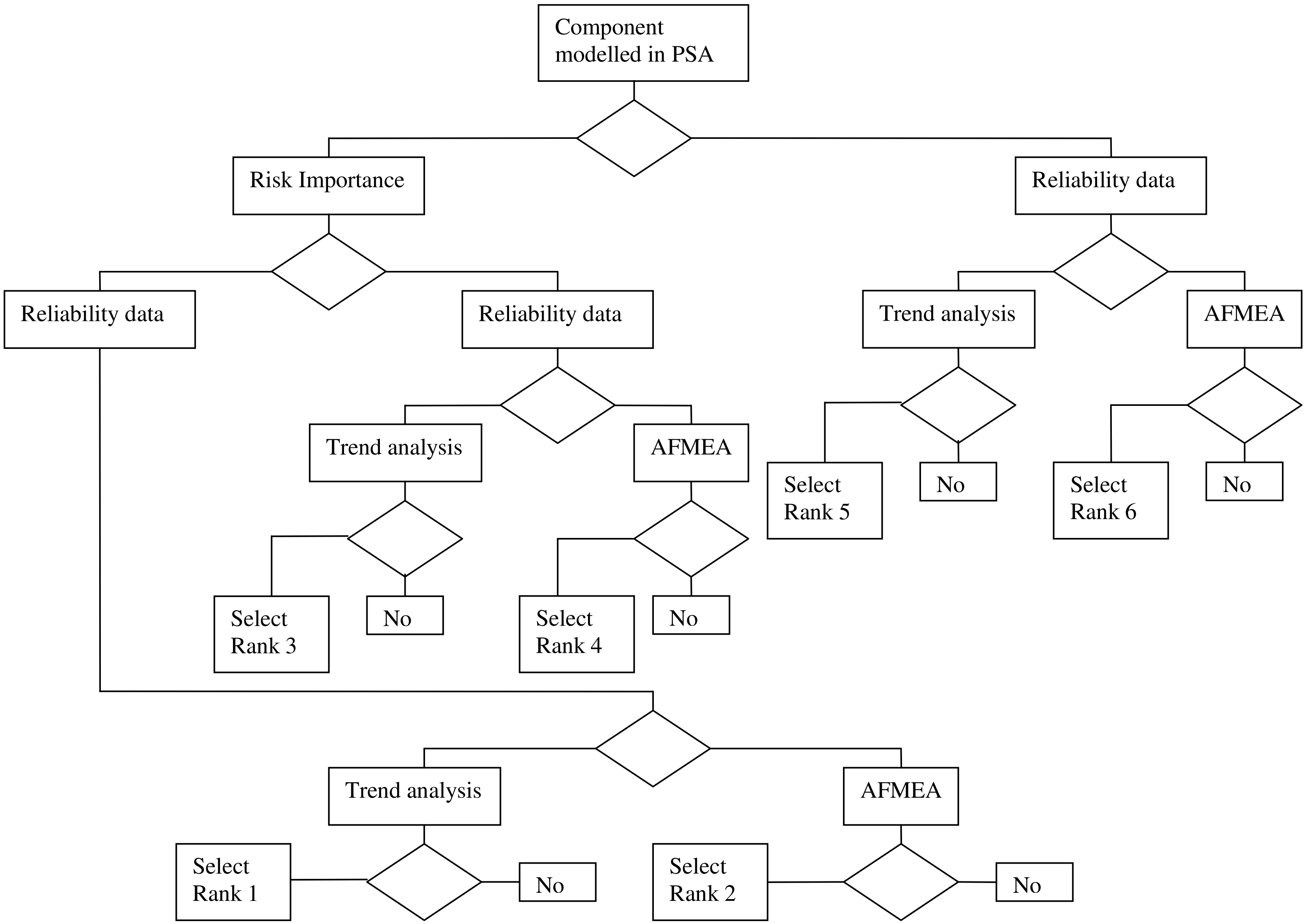
Component	Sub-component	Degradation mechanism	Working environement	FM	Probability	Importancy	Criticality
Valve	**Body/ bonnet**	Errosion wear	I	EL	L	M	2
		Fatigue (LC, HC)	I	EL	L	M	2
		General corrosion	I	EL	L	L	1
	Body-seat welding	Fatigue (LC, HC)	I	IL	L	M	2
		Pitting and crevice corrosion	I	IL	M	L	2
		SCC	I	IL	M	L	2
		Intergranular attack	I	IL	L	L	1
	Wedge - guide	Surface fatigue wear	I	FC/FO	M	H	6
		Abrasion	I	FC/FO	L	H	3
		Fatigue (HC, LC)	I	FC/FO	L	H	3
		Pitting and crevice corrosion	I	FC/FO	M	M	4
		SCC	I	FC/FO	L	M	2
	Wedge-seat	Fretting	I	FC/FO+IL	M	H	6
		Adhesion	I	FC/FO	M	H	6
		Abrasion	I	FC/FO+IL	M	H	6
		Erosion	I	FC/FO+IL	M	H	6
		Surface fatigue wear	I	FC/FO+IL	L	M	2
		Fatigue (HC, LC)	I	FC/FO+IL	L	H	3
		SCC	I	FC/FO+IL	M	H	6
		Fretting corrosion	I	FC/FO+IL	H	H	9
	Wedge-stem T-joint	Fretting	II	FC/FO	L	L	1
		Adhesion	II	FC/FO	M	L	2
		Abrasion	II	FC/FO	L	L	1
		Surface fatigue wear	II	FC/FO	M	H	6
		Fatigue (HC, LC)	II	FC/FO	L	H	3
		SCC	II	FC/FO	L	H	3
		Pitting and crevice corrosion	II	FC/FO	M	H	6
	Body-bonnet joint	Fatigue (HC, LC)	II	EL	L	H	3
		Pitting and crevice corrosion	II	EL	L	M	2
		Thermal ageing	II	EL	L	M	2
	Stem-packing	Fretting	II	FC/FO+EL	M	M	4

Figure 4.2 Example of stem gate valve ageing mechanisms ranking

Table 4.2 illustrates the final synthesis of evaluation including critical failure modes and effectiveness of surveillance strategy.

Table 4.2 AFMEA final conclusions

Critical Failure Modes	Effectiveness of operating tests to detect failure mode	Effectiveness of preventive maintenance to control ageing mechanisms
External leak	Monitored, direct and full control	Partial control of atmospheric corrosion every outage. Others ageing mechanisms are not controlled. As bad as old maintenance.
Internal leak	Indirectly checked once a month. Partial, direct check once per 6 outages	No ageing mechanisms are controlled. As bad as old maintenance.
Fail to close/fail to open	Partial, direct check once per 2 months. Full, direct check every outage	Partial control of ageing mechanisms related to end- and stork- switches every 6 outages. Full checking of ageing mechanisms of gear box every 12 outages. As bad as old maintenance.


Component modelled in PSA
Risk Importance
Reliability data
Reliability data
Reliability data
Trend analysis
AFMEA
Trend analysis
AFMEA
Select Rank 3
No
Select Rank 4
No
Select Rank 5
No
Select Rank 6
No
Trend analysis
AFMEA
Select Rank 1
No
Select Rank 2
No

APPENDIX 5 – INR APPROACH

The approach used two screenings:

- the first screening was related to system or structure level,
- the second one was performed at component level (evaluation of all component within the selected systems and structures),

and was performed in the following steps:

Step 1: *collection of necessary information*
The information consulted was as follows:

- component type, function and location
- manufacturer data (materials data)
- expected degradation mechanisms
- design specifications (service conditions, service life cycles)
- commissioning data
- environment information (temperature, humidity, radiation) and environmental qualification (qualified life, normal and DBE service conditions, operation requirements)
- dates and profiles of component loading, cycling
- operation mode (continuous, standby, intermittent)
- maintenance information (type of maintenance - corrective/ preventive, date and duration)
- work description (repair, refurbishment, replacement)

Step 2: *screening after the contribution of system to facility safety*
The entire list of facility systems was reviewed, to identify the systems important for safety or important for operation of other systems which are important for safety (support systems).
A system which did not belong to any of the above category was removed from the list for further analyses.
As a result, it was obtained a shorter list of systems to be evaluated at component level.

Step 3: *ranking of SSC which are important for safety* (using risk importance measures, or other arguments including expert judgment)
This step performed a screening after the impact of aged component failure to system function.
For ranking the components, the following indices were used:

SSC was considered as risk important if their calculated risk importance measure were above some specified values (RAW >2, FV>0.005), and they have allocated the index 3.
If the component is support component for the operation of a component which was considered as risk important, the experts allocated it the index 2.
The events with low risk importance measures values were considered as being related to non risk-significant components (index 1).

Step 4: *performing AFMEA* (indication of stress factors, ageing mechanisms, ageing failure modes, potential ageing effects for the selected components, effectiveness of maintenance activities, detection techniques)
This step was related to screening after the component susceptibility to age related failure.
This step evaluated the potential of ageing degradation to cause component failure, taking into account:

- *stressors and significance of known ageing mechanisms*
- *all applicable operating experience*

This step involved another screening process, related to ageing mechanism, and required knowledge of material degradation properties and operating stressors for a specific component.
The identification of the stresses acting on a component required the review of the design, operating, and environment conditions for the particular component.
The adequacy of current maintenance practices was evaluated for their potential in maintaining the risk contribution of these aged components within the acceptable value.
Existing methods for inspection, surveillance and monitoring were evaluated to determine whether they are effective for timely detection of ageing degradation before loss of safety function.

Since the degree of degradation was not recorded, maintenance records needed additive interviews with personnel and interpretation.

After the screening process, it was obtained a list of SSC which are sensitive for ageing and important from risk point of view.

The AFMEA was performed in the following steps:

- Getting an overview of the system:
  –Determination of component function
  -Identification of stress factors for each component and associated ageing mechanism

- Identification of relevant information for potential ageing failure modes of each component
  -Specification of ageing failure mode effect on the immediate function or item, on the system, and on the mission to be performed
  -Determination of occurrence probability for ageing failure
  –Determination of failure detection methods

- Evaluation of each ageing failure mode in terms of the potential consequences, probability of occurrence, probability of detection (allocating indices)
- Prioritization of components, recommend actions
- Documentation of analysis

The experts used as starting point a generic list, with potential stressors and corresponding ageing mechanisms.

For each failure caused by ageing, the effect has been described, and the severity of the failure has been quantified. The following developed tables should be read using the true-false concepts (1-true, 0-false), for each index.

Table A5.1 – Failure severity (S) indices

Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Incipient failure	1	1	0	0	0	0	0	0	0	0
Degraded failure	0	0	1	1	0	0	0	0	0	0
Critical failure	0	0	0	0	1	1	1	1	1	1
Local effect	0	0	0	0	1	1	0	0	0	0
Equipment effect	0	0	0	0	0	0	1	1	0	0
Global effect	0	0	0	0	0	0	0	0	1	1
Redundancy	1	0	1	0	1	0	1	0	1	0
No redundancy	0	1	0	1	0	1	0	1	0	1

To quantify the severity of the failure, the following cases have been considered: the component can or not have redundancy; the failure can be incipient, degraded or critical; and the failure can or not have impact on component, equipment or system level.

The scale goes from the value of 1 – the least severe failure (incipient failure, redundant component), to 10 – the most severe one (table 5).

The probability of failure occurrence has been quantified for each ageing mechanism.
For the failure probability quantification, the following had been taken into account: kind of stressors, material condition, and the efficiency of performed maintenance actions (if exist).

The scale goes from 1 – the least expected occurrence, to 10 – the most probable occurrence (table A5.2).

Table A5.2 – Failure occurrence (O) indices

Index	**1**	**2**	**2**	**3**	**4**	**5**	**5**	**6**	**7**	**8**	**9**	**10**
One ageing mechanism	1	1	1	1	0	0	0	0	1	1	0	0
More ageing mechanisms	0	0	0	0	1	1	1	1	0	0	1	1
Good material condition	1	1	0	1	1	1	0	1	0	0	0	0
Efficient maintenance	1	0	1	0	1	0	1	0	0	0	0	0
Medium maintenance	0	1	0	0	0	1	0	0	1	0	1	0
No maintenance	0	0	0	1	0	0	0	1	0	1	0	1

To quantify the probability of failure detection, the following had been taken into consideration: the type of failure annunciation (alarms, local indication or no indication), and the possibility of failure discovery (if exists) during inspection, testing or maintenance activities.
The scale goes from 1 – the highest probability of detection, to 10 – the smallest probability of failure detection (table A5.3).

The possibility of detection is referring to the ageing failure discovery, not to ageing mechanism detection. It was considered that a failure will have a higher probability of detection in case when is announced in the control room, and a low probability for detection was allocated in case when the failure can be discovered only by performing testing or maintenance actions.

Table A5.3 – Indices for probability of detection (D)

Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7**	**8**	**8**	**9**	**10**
Alarmed	1	1	1	1	0	0	0	0	0	0	0	0
Local indication	0	0	0	0	1	1	1	0	1	0	0	0
Inspected	1	1	0	0	1	1	0	1	0	1	0	0
Discovered through testing/ maintenance activities	1	0	1	0	1	0	1	1	0	0	1	0

Step 5: *rank the components which remains susceptible to ageing degradation*, despite the safeguard measures (using AFMEA results and expert judgment)

The RPN value was used to quantify the remaining sensitivity to ageing of the component (considering all the mitigation ageing measures).

<u>Related to sensitivity to ageing,</u> for indices scaling, it was considered the following:
- RPN higher than 200 gives a **HIGH** index for remaining sensitivity to ageing – case of very sensitive component to ageing (high degradation rate)
- RPN value between 100 and 200 gives a **MEDIUM** rank (ageing has a moderate impact on component operability)
- low RPN value (lower then 100) gives a **LOW** index for remaining sensitivity to ageing (ageing has a minimum impact)

As result, it was obtained a prioritized list of components which are susceptible to ageing (the components are prioritized considering the severity of components failure, the probability of failure occurrence and also the probability of detection).

Step 6: *using decision table, rank the components which are both susceptible to ageing and risk-significant* (using results from step 5 and step 3). This step identifies SSC candidates for further Ageing PSA analysis (using expert judgment).

Table A5.4 – Decision table

		Risk importance results		
		1	2	3
AFMEA results	LOW	**1LOW**	**2LOW**	**3LOW**
	MEDIUM	**1MEDIUM**	**2MEDIUM**	**3MEDIUM**
	HIGH	**1HIGH**	**2HIGH**	**3HIGH**

The final decision table summarized the impact of failure on facility safety and the results of AFMEA, having the following structure:

Table A5.5 - Component selection results

System	**Component**	**Rank due to risk importance measures**	**Rank due to AFMEA results**	**APSA selection**

SSC with risk importance rank of 3 or 2 and with AFMEA rank equal or higher than MEDIUM were selected for detailed studies.

APPENDIX 6 – ARMENIAN APPROACH

Work performed for Armenian NPP Unit 2 intended to select components for further age-dependent reliability models elaboration and incorporation of results into existing PSA model. Selection of components aimed to reveal those components which:
a) have significant role for nuclear safety and
b) have potential to be seriously affected by ageing.
Selection of components was decided to be performed based on following PSA elements:

- Systems
- Components
- Initiating events

Also common cause failures were checked to be sure whether final list is in compliance with CCF importance.
To identify and prioritize components potentially sensitive to ageing, the following technique was proposed:

- prioritize the components which are modeled in PSA using Risk Importance Factors,
- perform trend analysis of available reliability data,
- use qualitative assessment or Ageing Failure Modes and Effect Analysis (AFMEA) for a limited number of components.

All three steps are complementary.
Some of selected components were considered as newly installed. In that case they were deleted from final list (e.g. essential service water system equipment, fast steam isolation valves, etc.)

<u>Risk-based component selection</u>
According to international practice Fussel-Vessely importance factor (I_{FV}) was used as an indicator of components' risk importance.

$$I_{FV} = \frac{\sum_{j=1}^{c} S_j}{Q}$$

where S_j – frequency of minimal set of failures which could lead to core damage, c – amount of minimal cutsets which contains basic events with failures of particular equipment or human error, Q – total frequency of core damage event. Physical mean of this expression is proportion of minimal cutsets with particular failure and total frequency of core damage event.
Screening criteria was established at 0.5 % (I_{FV}>0,005) as it was recommended by NRC and EPRI methodology.
For initiators, screening criteria was based on fractional contribution of initiator. Those initiators which have more than 1E-06 [1/y] contribution in overall CDF, were screened in final list.
During discussions of this issue with APSA Network partners it was suggested to use also risk increase factor (RIF) as an indicator. Risk increase factor equals:

$$RIF = \frac{Q_{P=1}}{Q}$$

where $Q_{P=1}$ – conditional core damage frequency for particular failure, Physical mean of this expression is indication of total core damage frequency increase due to granted failure of particular equipment. As far as the incorporation of ageing effects into PSA aimed to highlight those components whose reliability could be affected by ageing, risk increase factor determine impact of those components, disabled by ageing effects, on total plant CDF.
Screening criteria was taken at RIF>1E+2.
Components selected for further ageing trend analysis were taken from both lists of safety important components determined by Fussel-Vessely importance (I_{FV}>0,005) and risk increase factor (RIF>1E+2) and combined into a one list. Component selection was conducted for both models optimistic and conservative in order to take into account all components that could be of high safety importance.
Based on presented approach the list of equipment relevant to safety for Armenian NPP Unit 2 was developed, and most important of the components in the list are those which are required to function

during LOCA initiators and secondary side steam leaks. Also some equipment devoted to function during transients came from optimistic model's analysis which shows importance of transient IEs.
Selected components were grouped into 2 major groups - active and passive components. The main reason of this diversification is different approaches for further ageing effect analysis: for active components statistical data could be derived and processed, whereas for passive components ageing effects are evaluated mainly using physical models.

<u>Ageing failure mode and effect analysis (AFMEA) procedure</u>
Procedure for Ageing Failure Modes and Effect Analysis consists of 8 major steps (Figure 6.2):

- grouping safety and safety related components taking into account design characteristics, operational stressors and environmental conditions, as well as test and maintenance strategy,
- in each group of similar components selection of most representative sample from ageing impact point of view (smaller design margins, higher operational loads, etc.),
- for each representative sample identification and justification of all possible ageing
- identification of failure modes (and it's effect to the system performance) which could occur due to the development of particular ageing mechanism,
- ranking the ageing mechanisms against their possibility of occurrence and development up to the failure,
- characterization of effectiveness of surveillance program (operational tests, inspections and maintenance actions) to control the ageing mechanisms and failure modes,
- for each failure mode conclusions on
  - mechanisms susceptible to appear in specific areas and zones of the component,
  - rank of effect of the failure mode and associated ageing mechanisms to the system and component performance (critical, non critical, etc.),
  - effectiveness of failure mode detection by operational tests and inspections,
  - degree of component renewal (elimination of ageing mechanisms effects) during preventive maintenance,
- documentation of results.

Basically main difference between AFMEA and traditional FMEA (FMEA - Failure Modes and Effect Analysis) analysis is appearance of new elements. FMEA represents following interlink "Part of

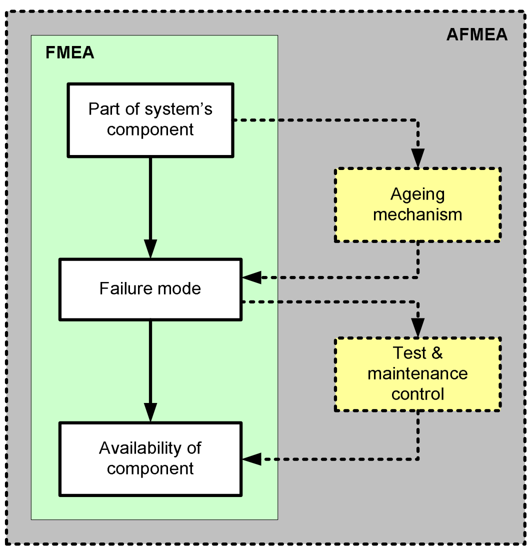
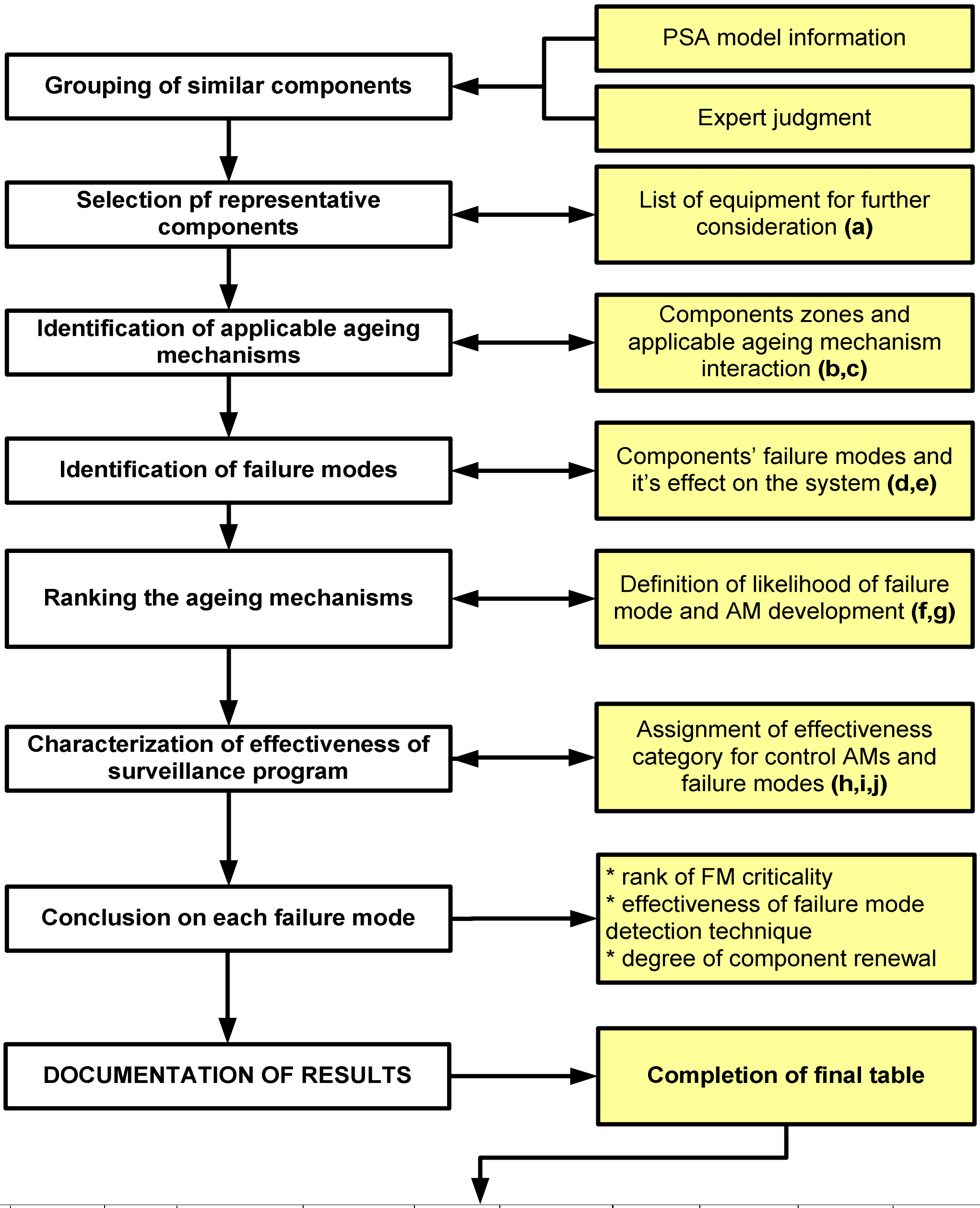


Figure 6.1 - Principal approaches of FMEA and AFMEA analysis

system's component - Failure mode - Availability of component", meanwhile AFMEA shows following interconnection "Part of system's component - Ageing mechanism - Failure mode – Test & maintenance control - Availability of component" (see Figure 6.1).



#	Component (a)	Failure mode (d)	Criticality of FM (e)	Zone of component (b)	Ageing mechanism (c)	Likelihood of FM (f)	Likelihood of AM devel. (g)	Ageing mechanism control (h)	FM control (i)	Conclusion (j)

Figure 6.2 - Detailed scheme of step by step implementation of AFMEA procedure

From practical point of view results of FMEA performed within PSA model development could be extensively used for AFMEA.
There is necessary a significant effort and resources for implementation of the tasks marked in "yellow" boxes on Figure 6.1, due to the large additional information that has to be analyzed in comparison with traditional FMEA implemented within PSA. Figure 6.2 shows detailed scheme of step by step implementation of AFMEA procedure. The key point of the procedure is qualitative set of criteria allowing to assign effectiveness category for particular ageing mechanism control procedures as well as it's likelihood estimation.

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Abstract
The guideline intends to provide a practical approach and to recommend the methods to be used in selection/ prioritization of components, systems and structures (SSC) sensitive to ageing and important from risk point of view in operating nuclear power plants.
The approach intends to ensure that the selection process will be carried out and documented in a uniform and consistent manner.
The methods suitable for selection are briefly presented, and their advantages and disadvantages are specified.
A list of generic ageing mechanisms, the factors favorable for their occurrence and some sensitive materials are provided in appendices.
In the appendices are presented also the specific approaches and criteria used for SSC prioritization and selection in case studies performed in the frame of Ageing PSA task 3 activities.
The guideline was developed in the frame of EC JRC Ageing PSA Network (APSA) activities.

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